AD719796

08773-62-T

HUMAN PERFORMANCE CENTER

DEPARTMENT OF PSYCHOLOGY

The University of Michigan, Ann Arbor

The Representation of the Stimulus in Character Classification

BLAKE LANE WATTENBARGER

Technical Report No. 22

August 1970

31

THE HUMAN PERFORMANCE CENTER

DEPARTMENT OF PSYCHOLOGY

The Human Performance Center is a federation of research programs whose emphasis is on man as a processor of information. Topics under study include perception, attention, verbal learning and behavior, short- and long-term memory, choice and decision processes, and learning and performance in simple and complex skills. The integrating concept is the quantitative description, and theory, of man's performance capabilities and limitations and the ways in which these may be modified by learning, by instruction, and by task design.

The Center issues two series of reports. A Technical Report series includes original reports of experimental or theoretical studies, and integrative reviews of the scientific literature. A Memorandum Report series includes printed versions of papers presented orally at scientific or professional meetings or symposia, methodological notes and documentary materials, apparatus notes, and exploratory studies.

T H E U N I V E R S I T Y O F M I C H I G A N

COLLEGE OF LITERATURE, SCIENCE AND THE ARTS

DEPARTMENT OF PSYCHOLOGY

THE REPRESENTATION OF THE STIMULUS IN CHARACTER CLASSIFICATION

Blake Lane Wattenbarger

HUMAN PERFORMANCE CENTER--TECHNICAL REPORT NO. 22

August, 1970

This research was supported by the Advanced Research Projects Agency, Department of Defense, and monitored by the Air Force Office of Scientific Research, under Contract No. AF 49(638)-1736 with the Human Performance Center, Department of Psychology, University of Michigan.

PREFACE

This report is an independent contribution to the program of research of the Human Performance Center, Department of Psychology, on human information processing and retrieval, supported by the Advanced Research Projects Agency, Behavioral Sciences, Command and Control Research under Order No. 461, Amendments 3 and 5, and monitored by the Behavioral Sciences Division, Air Force Office of Scientific Research, under Contract No. AF 49(638)-1736.

During part of the preparation of this document, the author was supported by a United States Public Health Service Predoctoral Traineeship under Grant No.571MH6738-12 to the Department of Psychology, University of Michigan.

This report was also a dissertation submitted by the author in partial fulfillment of the degree of Doctor of Philosophy (Psychology) in the University of Michigan, 1970. The doctoral dissertation committee was: Drs. R. W. Pew, Chairman, R. A. Bjork, W. M. Kincaid, and I. Pollack.

TABLE OF CONTENTS

ABSTRACT

A study was performed to determine the nature of the representations that are compared during the comparison stage in a character classification task. In such a task, _S_ is required at the beginning of each trial to memorize a small set of items called the positive set. A probe item is then presented and _S_ is required to make one of two responses indicating whether or not the probe item is a member of the positive set. Reaction time (RT) is the dependent variable.

Previous research has shown that RT is an increasing linear function of the size of the positive set for both positive and negative responses. From this fact it has been inferred that part of the RT is occupied by a serial comparison process during which some representation of the probe item is compared with similar representations of the positive set items, one after another. The slope of the linear function relating RT to positive set size is the time from the beginning of one comparison to the beginning of the next.

The present study was designed to determine whether the representations compared during the comparison stage are visual images (based only on sensory information) or verbal labels (based on the learned identity of the items involved). In one experimental condition (Name Identity), the positive set was defined by the names of the letters it included and both upper and lower cases of each letter were presented when the positive set was displayed. The probe letter was either upper or lower case, but its case was irrelevant to _S_'s response. In the other experimental condition (Physical Identity), each letter of the positive set was represented in upper or lower case, but not both. The positive sets contained equal numbers of upper and lower case letters, as nearly as possible. The positive response was appropriate if and only if the probe letter was physically identical with some character in the positive set (i.e., matched in both name and case). In the Control Cordition, the positive set and probe letters were all of the same case.

If comparisons were based on visual images, it was expected that for a given set size twice as many comparisons would be necessary in the Name Identity Condition as in the Control Condition, since separate comparisons would be required for the upper and lower case characters of each letter in the positive set. Thus the slope for the Name Identity Condition should be twice as great as the slope of the Control Condition. The slope of the Physical Identity Condition should be the same as for the Control Condition, since uniformity of case should be irrelevant for the comparison of visual images.

If, on the other hand, the comparison process were based on verbal labels, the Name Identity Condition should be the same as the Control Condition,

since in both conditions the name of the probe character, regardless of its case, would be abstracted before the comparison process began. In the Physical Identity Condition, however, each comparison should require more time, since more complex names (that discriminated between the upper and lower case characters) would have to be compared. Thus the slope of the Physical Identity Condition should be greater than the slope of the Control Condition.

The results revealed that performance in the Name Identity Condition was similar to performance in the Control Condition, and that the slope of the RT function was much greater on negative trials in the Physical Identity Condition when the probe item differed only in case from some character in the positive set than when the probe did not have the same name as any positive set character. It was concluded that the representations used for the comparisons stage are verbal labels.

CHAPTER I

ON THE COMPARISON STAGE IN CHARACTER CLASSIFICATION

A substantial body of research in recent years has been directed at the isolation and study of stages of information processing. Examples can be found in the areas of short-term visual memory (Sperling, 1967), selective attention (Egeth, 1967), and the psychological refractory period (Smith, 1967). These studies have frequently employed reaction time (RT) as a dependent variable, since it provides a unique insight into the temporal course of information processing. The use of RT to study processing stages is not new, however; it goes back to the earliest days of scientific psychology, when Donders (1868) attempted to measure stage duration by measuring RT for two tasks which differed only by the presumed presence of a particular stage in one task and its absence in the other. The revival of methods similar to Donders' was highlighted by a recent conference (see Koster, 1969) held exactly one century after the publication of Donders' main work on RT.

Donders' method fell into disuse because adequate tests were not available for two of the assumptions of the method. Donders assumed the existence of a succession of stages which did not overlap in time, so that their durations were additive components of RT. In addition, he assumed that stages could be added or deleted without affecting the durations of other stages. In an important theoretical paper, Sternberg (1969b) has proposed a method, the additive-factor method, which provides an explicit test of the first assumption and largely does away with the

need for the second. A full description of the method would be inappropriate here. Briefly, it involves the inference of the existence of stages from the pattern of interactions and non-interactions in factorial experiments. The properties of a stage so isolated are studied by manipulating its duration, rather than adding or deleting the entire stage.

The Character Classification Task

The focus of this paper is on the properties of one particular stage isolated by means of the additive-factor method. Sternberg (1969b) used the discovery and study of this stage to illustrate the application of his method.

The stage in question is the comparison stage in a character classification task. This task, used by Sternberg (1966) to study memory search, is quite simple. On each trial (or before a block of trials), S memorizes a small set of characters, usually digits in Sternberg's work. A test character is then presented and S makes one of two responses depending on whether or not that character is one of the memorized set. The Ss are encouraged to respond quickly, but emphasis is put on a low errror rate. Sternberg (1966) found RT, the time between onset of the probe and the response, to be a linear function of the size of the memorized (positive) set. This relationship held whether a new set was memorized on each trial (the varied-set design), or only before each block of trials (the fixed-set design). In the fixed-set experiment, with set size (s) taking the values one, two, and four, stimulus and response entropy were equated across set size, and possible differences among individual digits

were controlled. In the varied-set experiment, s took on all values from one to six. The RT functions for both negative and positive responses proved to be linear and parallel. The slope of the overall function was the same in both experiments.

From these data, Sternberg (1966) inferred the existence of a serial comparison stage, in which an internal representation of the test digit is compared sequentially with representations of the memorized digits. The comparison process must be exhaustive, with all possible comparisons made whether or not a match has been found; otherwise, the functions for negative and positive responses would not be parallel. If S stopped making comparisons as soon as a match occurred (a self-terminating search), he would, on the average, need to make only $(s + 1)/2$ comparisons on positive trials, and the slope of the negative response function would be twice as great as the slope of the function for positive responses. In addition, exhaustive scanning implies flat serial position functions. That is, if RT for positive responses is plotted as a function of the serial position of the matching character in the positive set, the resulting function should be linear with zero slope for each set size separately. This is because all possible comparisons are made on every trial; hence the order of the comparisons cannot affect RT, even if it is the same on every trial. A self-terminating strategy would also produce flat serial position functions if scanning began at a random location in the list from trial to trial. Hence flat serial position functions are a necessary, but not sufficient, condition for exhaustive

scanning. Sternberg's own studies have consistently yielded flat serial position functions (see Sternberg, 1969a).

Using similar paradigms, several investigators (Corballis, 1967; Morin, DeRosa, & Stultz, 1967; Morin, DeRosa, & Ulm, 1967) have found a recency effect in the serial position function, a result that is not consistent with exhaustive scanning. In contrast to Sternberg's procedure, these studies have employed rapid presentation of the memorized set and a very brief delay or no delay before presentation of the probe. Since Corballis (1967) found an increasingly strong recency effect with faster presentation, these differences probably account for the discrepency.

The same explanation will not account for the results of a similar experiment by DeRosa & Morin (1970). In their Exp. I, the positive set was constant for blocks of 112 trials, and always contained four digits. For positive trials, the serial position function was U-shaped, with the fastest RT's at the two center positions rather than the last position as in the other studies. However, the positive set digits were always consecutive and presented in increasing order (e.g., 3, 4, 5, 6). RT for negative responses was a decreasing function of the numerical distance of the probe digit from the positive set. The Ss may have learned, over a long block of trials, to base their responses on an intuitive numerical calculation rather than a scanning process. In a second experiment (DeRosa & Morin, 1970, Exp. II) using positive sets of four randomly selected digits, no serial position effects were obtained.

Exhaustive scanning seems to be an inefficient process. Why should S continue to make comparisons after a match has been found? Sternberg (1969a)

has confronted this question by suggesting a mechanism for which an exhaustive scan would be more efficient than a self-terminating one. Suppose a "comparator" makes the comparisons and sends a signal to a "match register" if and only if a match occurs. A central processor or "homunculus" controls the process and can either operate the comparator or examine the match register, but not both at once. If substantial time is necessary to examine the match register it could be more efficient to examine the register only once after an exhaustive scan than after each comparison of a self-terminating scan. This is, of course, only one example of a class of possible mechanisms for which exhaustive scanning would be more efficient that self-terminating scanning.

The average slope of the RT functions in both of Sternberg's (1966) experiments, about 38 ms per character, yields a comparison rate of about 26 characters per second This rate is much faster than the maximum rate of subvocal rehearsal, estimated to be between 3 and 7 items per second (Landauer, 1962). The Ss, then, must not be subvocalizing the positive set after the probe appears but before responding. They do, however, report rehearsing the positive set before the appearance of the probe. Rehearsal may serve only to keep the positive set fresh in memory.

The Comparison Stage

Subvocalization is much too slow to serve as the comparison process. This fact does not, of course, rule out the name of the character as a possibility for the kind of representation that is used; names might be compared, but by a much faster mechanism. What, then, is the nature of the comparison process? Sternberg has reported several experiments relevant

to this question. In the first (Sternberg, 1967), he attempted to determine the nature of the representations that are compared. Sternberg's experiment was again simple, but elegant. Degrading the test digit, he reasoned, should lengthen RT. But if the function relating RT to set size remained linear, degradation might increase either the slope or the intercept (or both) of the function. An increase in the slope would imply that the noise added to the stimulus was still present in the comparison stage, reducing the comparison rate; hence that representation must have had a strong sensory component and might have been a raw or refined image, a template, a physical feature list, etc. (Representations of this type will subsequently be referred to as images.)

Factors affecting stages other than the comparison stage should be reflected by changes in the intercept of the function; hence, an increase in the intercept would imply that some additional time was required to form the representation of the stimulus, which might then be free or nearly free of the degrading noise. Such a representation could be a highly processed visual image from which the noise had been removed by a filtering operation. It might, however, be an acoustic or articulatory encoding of the name of the character, some other verbal label, or an imageless concept of the character. (Representations of this type will be referred to hereafter as names or verbal labels.) Identifying the stimulus, which would be required for a name representation of it to be formed, should require more time for a degraded than an intact stimulus, accounting for the increased intercept of the function. Stated in terms of the additive-factor method, the question is whether the effect of

stimulus quality will interact with or add to the effect of set size. An interaction would imply that these factors affect the same stage, the comparison stage; additivity would suggest that they affect different stages.

Unfortunately, the results of the experiment were not as conclusive as one would hope. The Ss were run for two sessions, and a clear increase in the intercept was found on both sessions. But an intercept increase is ambiguous; it could result if the representation were either a highly processed visual image or a verbal label. On the first session only, there was a small but significant increase in the slope of the function. Sternberg argued that any evidence of noise in the representation, such as the small slope change on the first session, precluded any sort of name representation; he concluded that the representation was a highly processed visual image.

Investigating the generality of the high-speed scanning process, Sternberg (1969a, Exp. 4) provided another, but less direct, test of the kind of representation. With A. M. Triesman, he performed a character classification experiment using, instead of digits, a set of nonsense forms in one condition and a set of photographs of faces in another. The set size varied from one to four, and in both conditions the function relating RT to set size was linear. The comparison rates, about 22 and 18 items per second for forms and faces, respectively, were somewhat slower than the usual rate for digits, but the results were otherwise similar. In addition to being linear, the functions for negative and positive responses were equal in slope for both conditions, indicating exhaustive scanning. The stimuli in this experiment differed in several

important respects from digits. They were not familiar to the Ss, they were unordered and were not symbolic. The similarity of the RT functions in light of these differences suggests that the comparison stage is an important, common process. That these stimuli did not have well-learned names adds support for the conclusion that the representation used for the comparison process in the digit experiments was not the name of the digit.

In an experiment that may have forced S to scan through a list of digit names, Sternberg (1969a, Exp. 6) found a quite different scanning rate. In this study, Ss were required to locate a digit in the list rather than simply to determine whether or not it was present (hence the name "context-recall" for the paradigm). On each trial, S memorized a new list of three to seven digits. Then a probe digit, selected randomly from all the digits in the list except the last, was presented. The correct response was the spoken name of the digit which had followed the probe in the list. Thus the task did not involve classification, but it must have involved scanning, since RT was an increasing linear function of the length of the list. Analysis of the serial position functions indicated that Ss scanned serially through the list in the order presented, tended to start the scan at the beginning of the list, and stopped scanning when the test digit was located. Thus the search process was self-terminating, so the slope of the function relating RT to length of the list is half the time for one comparison. The obtained slopes in this experiment and a subsequent replication (Sternberg, 1969a, Exp. 7) were 124 and 113 ms per digit, or 226 to 248 ms per comparison, yielding a

search rate of about 4 to 4.5 characters per second. This rate is well within the range for subvocal rehearsal, and the hypothesis that Ss subvocalize the digit names cannot be discarded. If this rather slow, self-terminating process is characteristic of searching through a list of names, the context-recall experiment provides more evidence that the scanning process in the usual classification experiment involves some other representation.

One possible flaw in this argument is that the experiment involved as many responses as possible stimuli, rather than only two as in the previous character classification studies. To look into this, Sternberg (1969a, Exp. 8) devised a new task he called context-recognition. On each trial a new list of digits was memorized, as before, but the test stimulus was a pair of digits rather than a single digit. The two test digits always had appeared consecutively in the memorized list, but at the time of the test they could be either in the same order as their original presentation or the reverse order. The Ss indicated which by pulling one of two levers. As in the context recall experiment, the serial position curves indicated a self-terminating scan, and the function relating RT to set size was linear. The slope of this function, 114 ms per digit, agreed very well with the slope found in the context recall experiment. Response uncertainty seemed to have very little effect on the comparison rate.

Memory for the Positive Set

Another important question is the nature of the memory system that holds the positive set. There are at least three possibilities. Sperling (1960, 1967)

and others have studied a very short-term visual memory system which seems well suited to hold visual images of the positive set items. Several investigators have studied the properties of an intermediate (short-term) memory (referred to here as STM; e.g., Waugh & Norman, 1965; Bower, 1967; Atkinson & Shiffrin, 1968); it has been considered primarily as a store for verbal material. Permanent or long-term memory (LTM) is another possibility. Although usually studied with verbal materials, STM must hold whatever forms of information we are able to retain over extended periods, including musical tunes, photographs, smells, etc.; hence it could serve as the store for images of the positive set items.

The very short-term visual store can probably be ruled out immediately as a store for the positive set. Its duration, at most about 0.5 sec, is too brief to serve even for experiments using the varied-set design. In fixed-set experiments, Ss become thoroughly familiar with the positive set over a period of several minutes, and it surely enters LTM. It may also be maintained in STM, however, by the rehearsal process mentioned earlier. It is questionable whether there is sufficient time in the varied-set design for the positive set to enter LTM. The similarity of the results with the fixed- and varied-set procedures suggests that the same memory mechanism is used for both. By elimination, that mechanism is probably STM.

Sternberg (1969a, Exp. 5) performed an experiment to test this hypothesis. At the beginning of each block of trials, a positive set consisting of digits was memorized. At the beginning of each trial, a list of seven letters was presented sequentially, at a rate of two letters per second. On some trials, the list was followed by a signal to recall the

letters. On the remaining trials, a probe digit was presented, and S performed the usual classification task. It was intended that the list of letters would occupy STM to the exclusion of the positive set. The S would then be forced either to perform the search in LTM or transfer the positive set items to STM before scanning them. The results revealed a serial, exhaustive search process, but the search rate was only about half the usual rate, and the intercept was increased. The intercept increase may have been caused by S's uncertainty, until the probe was presented, about whether the trial would be a letter-recall trial or a digit-classification trial. These data indicate that the usual scanning process is not performed on items in LTM; hence it probably involves STM. The source of the reduction in scanning rate in this experiment cannot be deduced from available data. Sternberg (1969a) has favored an explanation based on a separate serial transfer of items into STM.

The results described to this point lead to a rather unexpected conclusion. Evidence has been put forward that the memorized items of the positive set are held in STM, perhaps through subvocal rehearsal of their names, until the probe item is presented and the comparison process begins. A visual image of the probe is employed for the comparisons. Logically, then, the representations of the positive set items must be visual images; otherwise, comparisons would be impossible. The unexpected conclusion is that visual images are held for a considerable time in STM, in contrast to the usual notion of STM as a store for verbal materials. Also surprising is the implication that these images are maintained in STM by rehearsal of their names. Since this conclusion rests on the finding that the

comparison stage involves a visual image of the probe, it is perhaps appropriate to examine additional evidence on that point.

Images or Names? More Data

The most direct evidence available is an attempt by Bracey (1969) to replicate Sternberg's (1967) experiment or the effect of stimulus quality. Sternberg used the same noise pattern to degrade the stimuli throughout the experiment, and Bracey reasoned that Ss might become proficient at filtering out that particular noise pattern during preprocessing. Consequently, he compared performance with intact and degraded stimuli for two groups, one with fixed noise (the same throughout the experiment), and the other with four different noise patterns. Neither group showed any difference between the slopes of the functions for intact and degraded stimuli, although degradation did cause an intercept increase for both groups. Bracey's failure to replicate Sternberg's intercept effect is not as conclusive as one might wish, however. Each function appeared to be negatively accelerated, although the deviations from linear trends were not statistically significant. In any case, failure to find an increase in the slope when the stimulus is degraded does not rule out a visual image representation. Even with varied noise, Ss may be able to remove the noise from the image before the comparison stage begins.

Two experiments similar to Sternberg's experiment with forms and faces (Sternberg, 1969a, Exp. 4) have been reported by Briggs and his colleagues (Briggs & Blaha, 1969; Swanson & Briggs, 1969). In such experiments, the idea is that if S uses a visual image of the stimulus for the comparison process, the comparison rate should be similar whether or not

the stimuli have well-learned names. Otherwise, the rate might be radically different or a different process altogether might be used. In the first experiment (Briggs & Blaha, 1969), both the size of the memorized set and the number of probe items presented on a trial were varied, and Ss were given extensive practice. The items were nonsense geometrical forms. For trials with only one probe the task was the same as Sternberg's, and the results were very similar. The functions relating RT to size of the memorized set were linear for both positive and negative responses. Equality of the slopes of the positive and negative functions indicated serial, exhaustive scanning. The slope, about 35 ms per item early in practice, agreed well with Sternberg's (1966) results for digits. The resulting comparison rate, about 29 items per second, was faster than Sternberg found for nonsense forms (22 items per second), but this difference may be accounted for by differences in the populations from which forms were selected for the two experiments, and by the extra practice in the Briggs & Blaha (1969) study. Briggs & Blaha (1969) found a decline in the slope of the function (hence an increase in the comparison rate) with practice.

In a very similar experiment, however, Swanson & Briggs (1969) found a logarithmic, rather than linear, increase in RT with the number of items in the positive set. The same sort of random forms were used, and the positive set varied in size from one to eight. Only a single test item was presented on each trial. The experiment was designed to examine the effect of accuracy criterion, which was varied between groups. The low accuracy group produced faster RT's and more errors (9% versus 0.5%), but

no interaction was found between the effects of set size and accuracy criterion. Separate functions for positive and negative responses were not reported. A simple serial comparison process will not account for the results of this experiment, as it will for the other two (Briggs & Blaha, 1969; Sternberg, 1969a, Exp. 4); hence the results of these experiments are equivocal with respect to the kind of representation used during the comparison stage.

Another way to investigate the code used for comparison is to select items for the stimulus set which are similar on some dimension that is suspected to be relevant, and see if that similarity causes interference, thereby slowing the comparison rate. Chase & Posner (1965) have reported one relevant experiment. Letters were used as stimuli, and one of their three conditions was a character classification task. The letters used were chosen to be either visually confusable, acoustically confusable, or neither (neutral). Visually similar stimuli should result in slower scanning if visual images were used; acoustically similar stimuli should cause slower scanning if names or verbal labels were used. The latter assumption was based on the familiar finding (see Conrad, 1964; Wickelgren, 1969) that items in STM are primarily encoded as acoustic or articulatory representations of their spoken names. They found no difference between the groups with acoustically similar and neutral stimulus sets, but the scanning rate was significantly slower for the group with visually similar stimuli. Thus the results supported the hypothesis that the representations compared were visual in nature.

In a similar experiment, Chase & Calfee (1969) varied modality of the positive set (visual or auditory) and modality of the test item (visual

or auditory) as well as the type of material (letters which were visually similar, acoustically similar, or neutral). Two experiments were performed, one a within-_Ss_ design, the other between-_Ss_; the varied-set procedure was used for both experiments. No effect of similarity was found in either experiment, in contrast to Chase & Posner (1965) who found an effect of visual similarity. However, scanning rates tended to be faster when the positive set and test items were presented in the same modality than when the modalities were different. The authors concluded that " . . . specific sensory information may reside in STM for a period of a few seconds and facilitate recognition of verbal materials (Chase & Calfee, 1969, p. 513)." Their conclusion is somewhat weakened, however, by the absence of any effect of similarity. If visual or auditory information were present, one should expect an effect of visual or auditory similarity.

This experiment raises an interesting possibility. Suppose _Ss_ are capable of using _either_ a sensory image or a verbal label. When modalities of presentation and test match, sensory images are utilized, saving the extra encoding time necessary to produce a verbal label or name. One would then expect an increased intercept when the modalities did not match, accompanied by a changed slope (since there is no reason to believe _a priori_ that the comparison rate for names would be exactly the same as for sensory images). The data of Chase & Calfee agree with the slope prediction, but the intercept differences tend to be in the opposite direction.

STM as a Store for Images

While it is not conclusive, the available evidence seems to indicate that a visual image of the probe is indeed used for the comparison stage. Thus the implication remains that visual images of the positive set items are stored in STM. Independent evidence that this is possible would be desirable. Posner (1969) and his colleagues have reported a series of experiments that seem to support the idea. In several studies (Posner & Keele, 1967; Posner, Boies, Eichelman, & Taylor, 1969) two letters were presented visually, separated by an interval of zero to two seconds. The Ss were required to press one of two keys, indicating whether or not the two letters had the same name. The letters could be physically identical, they could have the same name but be different in case, or be different letters. The difference in RT for the "same" responses between pairs which were physically identical and those which were the same in name only declined from about 90 ms to almost zero over the two second interval. Posner (1969) has argued that physical identity matches produce faster RT's because the matches occur on a more primitive level and involve only coded sensory information. Matches based on name identity, when case differs, necessarily occur at a higher level and are based on verbal labels. Proceeding to the higher level requires the extra time reflected by the RT difference.

The conditions of presentation of the visual stimuli were varied substantially among several studies (see Posner, 1969). Variation of the luminance of the display and the exposure duration, and the presence of a visual noise field in the interval between the letters had no effect

on the RT difference, although the absolute value of RT varied. These results make it doubtful that the sensory-level comparisons are based on an image in the very short-term visual store (Sperling, 1967). In one particular experiment (Posner, et al., 1969) the interval between letters (held constant at 0.5 sec) was either blank, contained visual noise, or contained a pair of digits. On trials when digits were presented, S was required to add them and report the sum, after responding to the second letter in the usual way. Both visual noise and the addition task yielded greater RT's than the blank field, but only the addition task eliminated the difference between RT for physical identity and name identity.

These results are consistent with the hypothesis that the sensory information is held in STM. The information is unaffected by variables that should interfere with images in the very short-term visual store, but is affected by a task (adding digits) that distracts attention. It is widely accepted that attention is required to maintain information in STM (Posner & Rossman, 1965; Crowder, 1967).

The problem remains, however, that the sensory information does not last very long. It has either disappeared or become ineffective after about two seconds. Storage of that duration would not suffice for character classification tasks, even with the varied-set procedure. The fixed-set procedure would require sensory storage lasting several minutes.

A possible escape from this dilemma is provided by a further series of experiments by Posner (Posner, et al., 1969). Under some conditions, evidence has been found that Ss may be capable of generating a visual code for comparison with an expected letter. The evidence comes from

studies, similar to those discussed above, in which the first letter was either visual or auditory. The second letter was always visual. In such an experiment, with the interstimulus interval constant at 0.75 sec., RT for the "same" response was as fast following an auditory first letter as the physical identity match RT following a visual first letter. The usual difference between physical identity and name identity RT's was found when the first letter was visual. The Ss could not, presumably, have responded as fast as they did after an auditory first letter unless the comparison was made at the primitive (sensory) level. For auditory first letters, upper and lower case second letters yielded equally fast RT's, even though the Ss were instructed to regard the auditory letter as upper case. This implies that Ss were generating images of both cases of the letter.

A second experiment was performed with interstimulus intervals of 0.0, 0.5, and 1.0 sec. The auditory matches were slower than visual physical identity matches at the zero interval, but just as fast after one second. This could result if a fraction of a second were needed to generate the visual image.

These results are interesting but puzzling. If S can generate visual images of both cases when the first letter is auditory, why can he not generate the opposite case (or both cases) when the first letter is visual? Further research is needed to clarify the generation process.

Suppose, however, that visual images can, under some circumstances, be generated. If images of the positive set characters were generated in the character classification experiments discussed previously, then

*S*s must have generated as many as six characters for a single trial (Sternberg, 1966). There is no evidence available that *S*s are capable of generating that many characters. On the contrary, there is some evidence that *S*s are able to form and hold no more than two visual images in STM. Posner & Taylor (1969, Exp. 2) presented one, two, or four letters for one second. Following a delay of 10, 500, or 1000 ms a probe letter appeared in one of the positions formerly occupied by a letter in the initial array. The *S*s responded "same" or "different" according to whether or not the probe letter had the same name as the letter in that position in the original array. Evidence was found (in the form of faster RT's for physical identity than name identity matches) for the availability of visual images for the two left-most array positions, but not for the third and fourth positions. Whether the limitation was encoding or storage is not clear. However, these data provide no assurance that *S*s might be able to generate and hold in STM a sufficient number of visual images for use in the comparison stage of the character classification task.

It has been assumed that comparisons that were not based on visual images (as when the letters differed in case) were based on the common name of the letters. Doubt is cast on this conclusion by a series of experiments by Taylor (1969). In his experiments, *S*s first saw a single upper case letter to be memorized. Three seconds later a probe letter and a second test letter, adjacent to the probe, appeared. The probe might match neither letter, the memorized letter, or the adjacent letter. The *S*s responded "same" if either letter matched the probe, and "different"

otherwise. In one experiment (Exp. V) both comparison letters were upper case, the probe could be either case on each trial, and Ss responded "same" if the probe had the same name as either comparison letter. RT was faster when the adjacent comparison letter was physically identical with the probe than when the adjacent letter only had the same name. When the memorized letter matched, RT was independent of the case of the probe. These results agree with the usual findings of Posner, and suggest that the adjacent match was based on visual images and the memory match on names.

Another experiment, however, seemed to contradict the latter conclusion. If memory matches were based on names, one would expect that saying the name of the stimulus during the three-second interstimulus interval would have no effect, or might facilitate RT if vocalization helped maintain a stronger trace in STM. Taylor found, on the contrary, that vocalizing the name of the first stimulus increased the RT for memory matches. In Exp. IV, employing nonsense forms and colors as well as upper case letters, Ss in one group vocalized the name of the stimulus while Ss in another group said the word "nine" during the interstimulus interval. Although vocalizing the name of the stimulus increased memory match RT's, it had no effect on the RT for adjacent matches. Saying "nine" had no effect on RT for either kind of match. The results of Exp. IV are difficult to explain. It is not clear what sort of representation would be interfered with by vocalizing the name of the stimulus, but not by saying "nine." The memory match in these experiments is quite similar, operationally, to the name identity match of Posner's

work. Hence it may be premature to conclude that such matches are based on a particular kind of coded information.

An experiment by Tversky (1969) seemed to indicate that Ss were able to generate visual images. The stimuli were schematic faces, constructed by using all combinations of values on three binary dimensions. The dimensions were shape (fat or narrow), eyes (filled or unfilled), and mouth (smiling or unsmiling). Names were constructed in a similar manner from two sets of two consonants and a set of two vowels ((D, G), (L, M), and (I, O)). The names (e.g., GILI, DOMO) were assigned to faces in a negatively correlated manner so that similar faces had dissimilar names and *vice versa*. The Ss were given extensive training on the assignment of names to faces. In the experiment proper, Ss were shown a single name or face followed one second later by a second name or face. The Ss responded "same" or "different" by pressing one of two buttons, and RT was measured. The "same" response was appropriate if the two stimuli were physically identical or, when they were in different modalities, if the name corresponded to the face. Within each block of trials one of the modalities predominated for the second stimulus (e.g., 79% faces and 21% names). RT was faster when the second stimulus was in the predominant modality than when it was in the non-predominant modality. This suggests that Ss encoded the first stimulus in the modality they expected for the second stimulus. Hence in blocks when the second stimuli were predominantly faces, Ss encoded the first stimulus pictorially whether it was a face or a name.

This study suggests that Ss are able to hold, and even generate, pictorial information. There may be an alternative interpretation, however. Since the schematic faces were very simple and easily specified by a verbal description, the pictorial representations could have actually been verbal (e.g., "fat-dark-smiling") rather than true sensory images. Comparing such a verbal description to a similar encoding of the second stimulus might require more time than comparing two sensory images. In fact, the obtained RT's for matches presumed to be pictorial were substantially longer (630 to 750 ms) than the physical identity matches under similar conditions in Posner's work (375 to 525 ms, see Posner, et al., 1969). But even if Ss generated and held true visual images in STM, they generated only one on each trial and held it for only one second. Again, Ss in the character classification experiments would have to generate several images and hold them for a longer time.

Summary

A number of studies have been reviewed which indicate the existence of a high-speed scanning process in STM. Although there are some discrepancies in the literature, the basic phenomenon and the conditions under which it can be observed are reasonably well established. The scanning process is both serial and exhaustive. It occurs with familiar, meaningful materials and unfamiliar materials alike. The scanning rate is much faster than the maximum rate of subvocal rehearsal. High-speed scanning apparently does not occur when S must locate an item in memory, relative to other items, but only when he must simply determine an item's presence or absence.

Of particular interest has been the kind of representation of the stimulus (and hence of the memorized items) used for the comparison stage. The possible representations can be divided into two classes, those based on sensory information alone (images) and those based on a learned name, label, or concept (names). Data from several sources have suggested some form of image representation. Other experiments, however, have cast doubt on *S*'s ability to hold a sufficient number of sensory images in STM for a sufficient time for the scanning process to take place.

The present study was undertaken to investigate further the kind of representation used in the comparison stage. The experimental strategy was based on the distinction, employed by Posner, between name identity and physical identity of letters. The question was whether, in a character classification task, scanning for a physical identity match or for a name identity match would produce a scanning rate more similar to a control task in which *S* could use either strategy.

CHAPTER II

METHOD

Subjects

Twenty-nine women students at the University of Michigan served in the experiment as paid volunteers. They were all right-handed.

Apparatus

Feedback information and stimuli were presented via a Digital Equipment Corporation Type 30 Cathode Ray Tube Display, controlled by a PDP-1 computer. A chair was provided for *S* facing the display. A response keyboard was positioned on a sloping surface immediately below the display screen and comfortably within *S*'s reach. The resulting distance between the screen and *S*'s eyes was approximately 70 cm (28 in.). Two response keys were used; each required a minimum force of about 0.3 newtons (31 gm) to be activated. The *S*s were instructed to use their two forefingers to press the keys. The *S* wore earphones through which low level white noise was presented to mask distracting outside noises. The *E* could interrupt the white noise and speak to *S*, who could reply through a nearby intercom. The *S*'s room was dimly lighted.

Experimental Design and Procedure

Each condition in the experiment was fundamentally a character classification task. On each trial *S* was required to memorize a set of letters (the positive set) and then respond to a probe letter by pressing one of the two keys indicating whether or not the probe letter was a member of the positive set. A new positive set was presented on each trial. To eliminate the possibility that the positive set would spell

a word, no vowels were used. The ten consonants employed (B, D, G, H, J, M, N, Q, R, and T) were selected for maximum dissimilarity of their upper and lower case representations. These letters were specially programmed to resemble Metro Thin No. 2 type face, which was chosen for its simplicity and for the normative appearance of its letters (for examples, see Fig. 1).

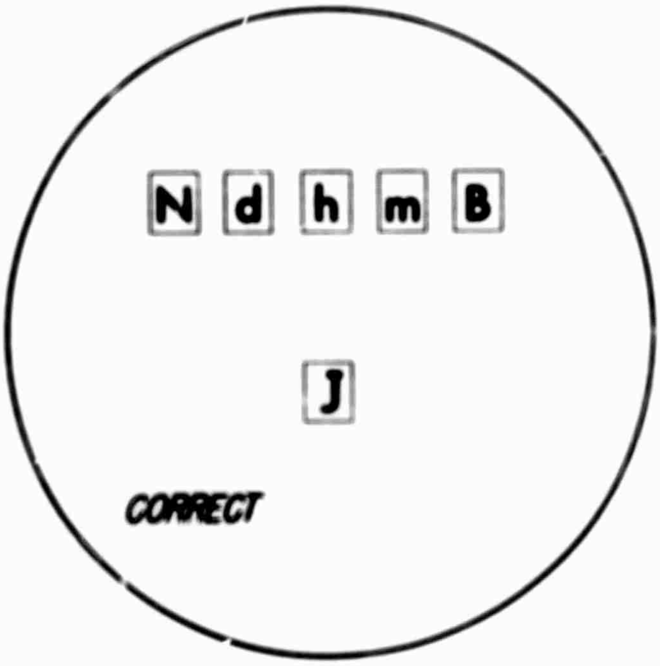

Fig. 1. The stimulus display on a typical trial in the Physical Identity Condition. The stimulus events actually occurred sequentially, as described in the text.

Upper case letters were 2.4 cm (0.95 in.) high. Lower case letters varied from 1.4 cm (e.g., m) to 2.6 cm (j) high (0.55 to 1.0 in.).

The experiment was run in blocks of 44 trials. The size of the positive set varied randomly from one through five across trials; each block of trials consisted of four warm-up trials followed by forty experimental trials, including eight with each positive set size. A positive response was appropriate on half of the trials with each set size.

There were two experimental and two control conditions in the experiment. In one control condition the letters in the positive set and the probe letter were all upper case. The other control condition was the same, except all of the letters were lower case. In one experimental condition (Physical Identity), half of the letters in each positive set were upper case and half were lower case as nearly as possible. With set size one, three, and five, each case predominated in the positive set on half of the trials within each block. The probe letter was upper (lower) case on half of the trials for each set size within a block. In this condition, S was required to give the positive response (by pressing the right-hand key) if and only if the probe letter physically matched some character in the positive set (i.e., was the same name and the same case). Consequently there were two kinds of negative (left key) responses. On half of the negative trials with each set size the probe letter had the same name but was different in case from some letter in the positive set. These will be referred to as case-mismatch (CM) negative trials. On the remainder of the negative trials, the probe did not have the same name as any letter in the positive set (pure negative trials). In the second experimental condition (Name Identity), the positive set was defined by the names of the letters it contained. When the positive set was presented

to S at the beginning of each trial, both the upper and lower case representations of each letter were displayed, simultaneously, with the lower case appearing immediately below the upper case on the screen. The probe letter was upper (lower) case on half of the trials, but its case was irrelevant. The S gave the positive response if its name was the same as the name of some letter in the positive set and the negative response otherwise.

Each S served in three conditions, one of the control conditions and both experimental conditions. The Ss were run individually for two sessions of one and one-half hours, about one week apart. A session consisted of seven blocks of trials, a practice block followed by two blocks under each of the three conditions. The control condition in which the S did not serve was used for the practice block. All six possible orders of administration of the three conditions were used. To accomplish this, Ss were divided into eight groups of three Ss each, four groups under each control condition. The order of administration of conditions for the upper case control groups was counterbalanced with one latin square. The orthogonal latin square was used to counterbalance the groups having the lower case control condition. Each S received the conditions in the same order in both sessions. A rest of about 30 sec was allowed between the blocks of each condition, with a five minute rest between conditions.

Figure 1 illustrates the display on a typical trial. Each trial began with sequential presentation of the positive set. Each letter was surrounded by a rectangle 3.1 cm high and 2.2 cm wide (1.2 by 0.87 in.) and was displayed for 1.2 sec. The area enclosed by the rectangle was then made solid white for 0.5 sec to mask the trace of the letter left on

the screen by the slow-decay phosphor (P7) used for this display. The next letter in the positive set appeared immediately on termination of the mask of the previous letter. The letters were presented in a row across the upper part of the screen, always beginning at the exteme left side. A delay of 2.0 sec intervened between the last letter in the positive set and the warning signal, which was the appearance of the rectangle in the center of the screen. One second later the probe letter appeared in the rectangle; both the rectangle and the letter remained on the screen until S made her response. Immediately following the response, the word "correct" or "error" appeared in the lower left corner of the screen for 2.0 sec informing S about the accuracy of her response. Between termination of the feedback and the beginning of the next trial there was a delay of 0.5 sec. The spatial position in the positive set of the letter which matched the probe on positive trials was varied randomly, under the constraint that each serial position was sampled equally often as nearly as possible. In the Physical Identity Condition the spatial distribution of upper and lower case letters in the positive set was varied unsystematically. The probe letter for each trial was chosen randomly from the appropriate set (the positive set or its compliment).

At the beginning of the first session, S was given a general description of the task; before the first block of each condition, she was given additional instructions pertaining to that specific condition (verbatim instructions are given in the Appendix). The S was instructed regarding accuracy as follows:

> As you can see, the task is easy and you should be able to respond correctly on almost every trial. It is important that you do so. I want you to respond as quickly as you can while maintaining a *high* level of accuracy. Try to be fast, but don't try so hard that you make unnecessary errors.

The *S* was reminded of the general instructions at the beginning of the second session, and the specific instructions were repeated before each condition. Any *S* who made more than 18 errors in the 264 trials of the six experimental blocks on either session was discarded. The *Ss* were not informed of this criterion in advance. Five of the original 24 *Ss* were excluded by the error criterion; new *Ss* were run to replace them.

CHAPTER III

RESULTS

The latency data from the practice block, the first four trials in each experimental block, and all of the [illegible] incorrect responses were discarded. For each S, a mean and a median were calculated for the remaining responses under each condition of positive set size (s), condition, session, and response. The following analysis is based on the resulting means. Preliminary analysis using medians revealed no essential differences, although the medians were typically somewhat smaller than the means, reflecting the tendency of reaction time distributions to be positively skewed.

Mean reaction time is plotted as a function of set size for each condition separately in Fig. 2. The functions for the Upper and Lower Case Controls and Name Identity Conditions appear to be well described by straight lines. The least-squares criterion was used to fit the lines shown, and they account for 95.6%, 99.6% and 99.2% of the variance in the Upper Case Control, Lower Case Control, and Name Identity Conditions, respectively.

The five points for the Physical Identity Condition are not so easily described. The last four (s = 2-5) are well fit by a straight line, but the point at s = 1 is well below the line through the others. Several considerations make it seem reasonable to ignore this point in the data analysis. First, a primary goal of the study was to measure the *rate* of search through memory under that experimental condition, and it seems clear that the slope of the best fitting straight line through the other four points is a better estimate of the search rate than would be the slope of a

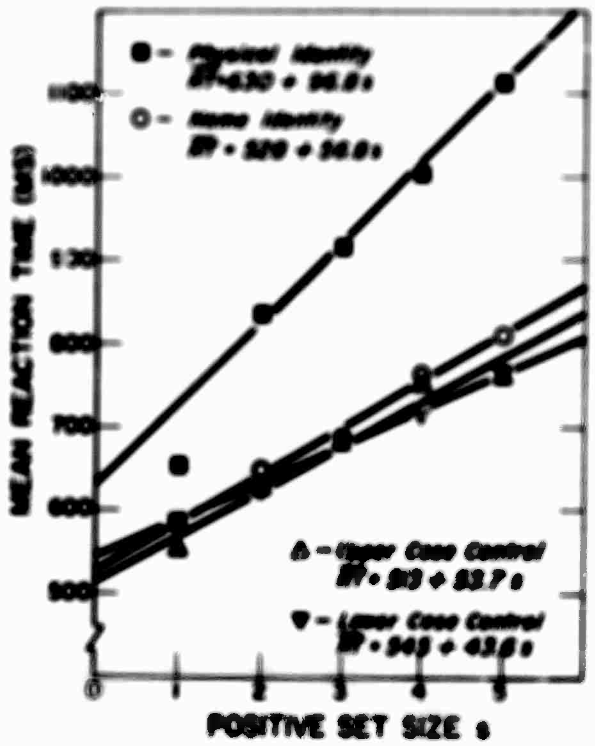

Fig. 2. Mean RT as a function of set size for each condition, averaged over subjects, sessions, and responses. Equations of the straight lines, fitted by the least-squared method, are given. For the Physical Identity Condition, the line is based only on the points for s = 2-5; the omission of the point at s = 1 is discussed in the text.

line through all five points. Second, there was unavoidable confounding in the data for s = 1 in this condition. Since the positive set contained only one letter, only one case (upper or lower) could be represented in it. Consequently, a failure of the case of the probe letter to match the case of the positive set was sufficient information for a negative response,

without reference to the names of the letters involved. The stimulus sequences in this condition were designed so that the negative trials included equal numbers of upper and lower case probes and equal numbers of case matches and mismatches, as well as equal numbers of the two types of negative trials. In addition, at $\underline{s} = 1$, there were equal numbers of upper and lower case positive sets. As a result of these restrictions, the case of the positive set always matched the case of the probe on pure negative trials, and only CM negative trials involved a case mismatch. If $\underline{S}$ could make a preliminary test for case, one would then expect a reduction in reaction time for CM negative responses at $\underline{s} = 1$. This prediction is confirmed by Fig. 3, in which the CM negative, pure negative, and positive response functions are plotted separately for the Physical Identity Condition. Suppose then that $\underline{S}$ found the case of the probe matched the case of the positive set. On two thirds of such trials the positive response was correct; the remaining trials were pure negative trials. The imbalance should have the effect of reducing somewhat the mean positive reaction time and increasing the mean pure negative reaction time, if $\underline{S}$ could take advantage of the redundancy. Again, Fig. 3 confirms the prediction. This argument casts some doubt on the reliability and hence the usefulness of the data at that point. For these reasons, the data at $\underline{s} = 1$ in the Physical Identity Condition were excluded from further analysis.

A straight line function relating reaction time to set size was calculated by the least-squares method for each combination of subject, condition, session, and response. Subsequent tests were performed on the resulting slopes and intercepts.

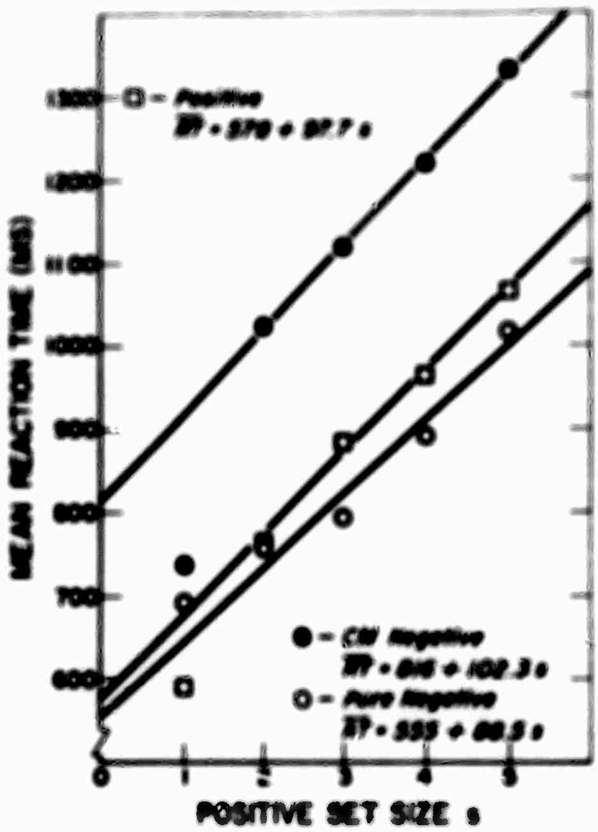

Fig. 3. Mean RT as a function of set size for positive, CM negative and pure negative responses of the Physical Identity Condition, averaged over subjects and responses. The straight lines shown were fitted by the least-squares method to the points for $\underline{s}$ = 2-5 only. Omission of the points at $\underline{s}$ = 1 is discussed in the text.

Since two-tailed $\underline{t}$ tests revealed no significant difference between the two control conditions, either in slope, $\underline{t}(6) = 1.688$, $\underline{p} > 0.1$, or intercept, $\underline{t}(6) = 0.378$, $\underline{p} > 0.3$, they were combined and treated subsequently as a single condition (Control). These and all other $\underline{t}$ tests were performed on the values obtained by averaging across the three $\underline{S}$s in each of the

eight groups formed for the purpose of counterbalancing the order of administration of conditions (see Chapter II).

An analysis of variance performed on the slopes revealed a significant main effect of Conditions $F(2,46) = 24.791$, $p < 0.001$, and a significant three-way interaction of Conditions x Sessions x Responses, $F(2,46) = 3.816$, $p < 0.05$. The main effects of Sessions and Responses and all three two-way interactions failed to reach significance. A Newman-Keuls test revealed that the Physical Identity Condition was significantly different from the Control and Name Identity Condition, which were not different from each other.

The three-way interaction resulted from a difference among conditions in the change in the relationship between mean slopes for positive and negative responses as a function of practice. The Control Condition showed a small but significant difference, $t(7) = 2.435$, $p < 0.05$, between the slopes for positive and negative responses on the first session, but no difference on the second session, and no difference for the combined sessions. The Name Identity Condition showed no difference on the first session, but a substantial difference, $t(7) = 5.059$, $p < 0.01$, on the second session and a significant overall difference, $t(7) = 2.446$, $p < 0.05$. In those cases where the differences between the slopes for positive and negative responses were significant, the positive response slopes were smaller. The Physical Identity Condition showed no difference on either session between the positive function and the combined negative functions. The slope of the CM negative function did not differ significantly from the slope of the pure negative function on either session.

An analysis of variance performed on the intercepts revealed significant main effects of Conditions, $F(2,46) = 11.165$, $p < 0.001$, Sessions, $F(1,23) = 5.554$, $p < 0.05$, and Responses, $F(1,23) = 20.854$, $p < 0.001$, but no significant interactions. A Newman-Keuls test again indicated that the main effect of Conditions was due entirely to the Physical Identity Condition, which was greater than either of the others. In the Physical Identity Condition, the intercept of the CM negative function was significantly greater than the intercept of either the pure negative function, $t(7) = 3.667$, $p < 0.05$ or the positive function, $t(7) = 3.776$, $p < 0.05$. The difference between the pure negative and positive functions was not significant.

The percentage of incorrect responses as a function of set size is shown for the three conditions in Table 1. The overall error rates were

TABLE 1

PROPORTION OF INCORRECT RESPONSES BY SET SIZE

FOR EACH CONDITION AND RESPONSE TYPE

Condition and Response Type	Set Size 1	2	3	4	5
Control					
Positive	0.023	0.013	0.018	0.036	0.042
Negative	0.021	0.021	0.018	0.029	0.021
Name Identity					
Positive	0.010	0.034	0.036	0.023	0.052
Negative	0.018	0.023	0.016	0.023	0.070
Physical Identity					
Positive	0.026	0.034	0.086	0.086	0.104
CM Negative	0.042	0.069	0.078	0.094	0.141
Pure Negative	0.021	0.000	0.005	0.005	0.057

2.4%, 3.1%, and 6.0% for the Control, Name Identity and Physical Identity Conditions, respectively. The error rate increased monotonically with set size in the Physical Identity Condition, but did not change systematically with _s_ in either the Control or the Name Identity Conditions.

CHAPTER IV

DISCUSSION

The experiment reported here included a Control Condition that should serve as a replication of earlier character classification experiments. The results of the Control Condition will be discussed in that light. Since the present results have implications that conflict with some tentative conclusions drawn from previous research, that research must be re-examined. But the main reason for performing the experiment was to discover the nature of the representation used during the comparison stage. Hence the discussion will begin with that question.

Evidence for a Name Code

Three aspects of the data clearly indicate that a name or verbal label representation, not a visual image, is used during the comparison stage. They will be discussed separately.

Searching for Name Identity

The Name Identity Condition was designed to provide one test of the kind of representations used. Using name representations rather than images should facilitate scanning in this condition. For example, suppose that the positive set on a particular trial was "bee, gee, tee." On the display, *S* would see:

B G T

b g t

Suppose also that the probe was "T." If *S* used name representations, she would first identify "T" and find its name, "tee." Three comparisons would

be necessary, "tee" with "bee," "gee," and "tee." If, on the other hand, a visual image of "T" were compared with the positive set, six comparisons would be necessary. Separate tests with the upper case and lower case characters would be required for each letter in the positive set. Consequently, the slope of the function relating RT to set size in this condition is the time for either one name comparison or two image comparisons. In contrast, the slope of the RT function in the Control Condition is the time for either one name comparison or one image comparison. For example, suppose that in the Upper Case Control Condition on a typical trial the positive set was (B, G, T) and the probe was "T." Then three comparisons would be necessary whether S used name representations or images. So if S used name representations in both the Control and Name Identity conditions, the slopes of the RT functions should be equal. If S used image representations in both conditions, the slope of the RT function for the Name Identity Condition should be twice the slope for the Control Condition. The obtained slopes, averaged across positive and negative responses, were equal, implying that S used name representations in both conditions.

However, a considerable difference (28.4 ms per letter) was found between the slopes of the positive and negative response functions on the second session for the Name Identity Condition. This difference was clearly significant, and produced a significant difference for the two sessions combined, despite the absence of any difference on the first session. The difference on the second session is large enough to suggest a self-terminating search process, since the slope of the negative function was almost twice as great as the slope of the positive function. Closer

examination of the data does not support this interpretation, however. Most of the difference is accounted for by six Ss, whose positive response functions were nearly flat (zero slope) on the second session. Several attempts were made to discover the source of this unusual finding, but all of them failed. The overall level of the RT's of those six Ss was not unusually long, and they performed normally in the Control Condition on the second session. The order in which those Ss received the conditions gave no hint of any sequential effect. Thus no explanation could be found for this anomaly in the data.

Two comparisons can be made between the Name Identity Condition and the Control Condition that are not confounded by the difference in slopes for the Name Identity Condition. First, the two conditions can be compared on Session One, when there was no difference between negative and positive slopes for the Name Identity Condition. The difference of 16.7 ms per item was marginally significant ($t(7) = 2.463$, $p < 0.05$) by a two-tailed test. Secondly, the negative response functions combined across sessions can be compared, since the slope of the negative function gives the time per comparison even for a self-terminating process. The difference of 15.0 ms per item just failed to reach significence ($t(7) = 2.245$, $p > 0.05$). Thus there is at least some evidence of a difference between the scanning rates in these conditions.

In light of this difference, the overall similarity of the results of these conditions must be interpreted with caution. It cannot be argued that performance in the Name Identity Condition was identical to performance in the Control Condition. In the context of the results of the Physical

Identity Condition, however, it seems reasonable to conclude that the representations used for comparison in the Name Identity Condition were not visual images and must have been names.

Searching for Physical Identity

An independent test of the nature of the representation was embodied in the Physical Identity Condition. Use of image rather than name representations should facilitate RT in this condition. Returning to the example, suppose on a particular trial the positive set was {b, G, t} and the probe was "T." The S could make either three image comparisons or three name comparisons. Making image comparisons should cause no difficulty, but suppose S used names for the comparisons. If the probe "T" were identified and named only "tee," an error would result. The S would compare "tee" with "bee," "gee," and "tee," find a match, and make the positive response. The response would be an error, of course, since "t" and "T" do not match physically. To avoid such errors, S would be forced to use more complex names, such as "big tee" for the probe, that included an indication of the cases of the letters. It seems reasonable to suppose that comparing these more complex names should require more time than comparing simpler names. So the slope of the RT function in the Physical Identity Condition represents the average time for either one image comparison or one comparison of complex names. Turning again to the Control Condition, the slope is the time for either one image comparison or one comparison of simple names. Thus if S used image representations in both conditions, the slopes should be equal. If names were used the slope of the Physical Identity Condition function should be greater than the slope of the Control

Condition function. In fact, the latter was the case, again indicating that names were used for the comparison process.

CM Negative Responses

The final aspect of the data favoring name representations over images also comes from the Physical Identity Condition. In that condition there were two kinds of negative trials. CM negative trials were those trials in which the name of the probe was the same as one of the letters in the positive set, but the cases were opposite. In pure negative trials, no letter in the positive set had the same name as the probe. If images were compared, this difference should cause no difficulty, since the letters used in the experiment were selected on the basis of the visual dissimilarity of their upper and lower case representations. If names were compared, on the other hand, one might expect some interference. If Ss used the usual names of the letters plus some indication of case, the representations for the upper and lower case versions of the same letter would be identical in many respects. The resulting interference should affect only the intercept of the RT function, since it occurs only once on each CM negative trial, regardless of set size. Thus the predictions are that CM negative and pure negative RT functions should not be different if images are used; the CM negative function should have a greater intercept than the pure negative functi. if names are used. The data agree with the latter prediction, again implying that the representations used are names.

Other Evidence Regarding Scanning

The Control Condition was intended as a replication of the original studies of Sternberg (1966) as well as the experimental baseline for the

present study. On the whole, the results agreed with Sternberg's (1966) findings. The slope of the overall RT function, 48.6 ms per item, was somewhat greater than Sternberg found. The difference is probably accounted for by the difference in the stimulus set; digits were employed in Sternberg's experiments, and letters were employed in the present study. Letters were also used in the Chase & Calfee (1969) study, and with visual presentation and test, slopes of 47.6 and 41.1 ms per item were found, in close agreement with the present results.

One aspect of the present data is in conflict with previous results. There was a significant difference between the slopes of the negative and positive response functions on the first session in the Control Condition. Inequality of the slopes of these functions is evidence against exhaustive scanning. The difference was small, however, and for both sessions combined, there was no significant difference between the slopes of the two functions. Consequently, it is doubtful that this result is sufficiently strong to represent a challenge to previous studies in which the slopes have been found to be equal (see Sternberg, 1969a).

Analysis of the intercepts of the RT functions revealed main effects of Conditions, Sessions, and Responses (positive versus negative), and no interactions. All three main effects were expected. The significant reduction in the intercepts with practice (the main effect of Sessions) was also found by Sternberg (1967). The main effect of Conditions was found to be entirely due to the Physical Identity Condition. The main effect of Responses was also expected, since all of the Ss were right-handed

and the positive response was always made with the right hand. Response times are typically somewhat shorter with the dominant hand.

The analysis of variance of the intercepts did not reveal all of the important aspects of those data, however. To perform the analysis of variance it was necessary to pool the pure negative and CM negative responses in the Physical Identity Condition. Hence the analysis could not reveal the relationships among the intercepts of the pure negative, CM negative, and positive response functions. It has been pointed out (see Fig. 3) that the intercept of the CM negative function was substantially greater than the other two. And while there was no significant difference between the intercepts of the pure negative and positive functions, the intercept of the positive function was numerically larger. If the CM negative responses alone suffered from the interference discussed previously, resulting from a partial match of verbal labels, then one might expect the intercepts of the pure negative and positive functions to stand in the same relationship as the intercepts of the negative and positive functions in the Control Condition. In that condition, the intercept of the positive function was less than the intercept of the negative function. Hence one would expect the intercept of the positive function in the Physical Identity Condition to be less than, instead of greater than, the intercept of the pure negative function. Either the intercept of the positive function was unexpectedly high or the intercept of the pure negative functions was unexpectedly low.

Which of these possibilities was the case can be determined by comparing these intercepts with their counterparts in the Control Condition.

The intercepts of the positive functions were 497 ms and 575 ms in the Control and Physical Identity conditions, respectively. The intercept of the negative function in the Control Condition was 561 ms as compared to 555 ms for the pure negative function in the Physical Identity Condition. Clearly, then, the negative functions agreed and the intercept of the positive function was unexpectedly high in the Physical Identity Condition.

This finding suggests that the positive responses in the Physical Identity Condition also suffered from some interference. The CM negative and positive trials in this condition had one thing in common; the usual name (ignoring case) of the probe matched the usual name of some letter in the positive set. Such a match was always sufficient for a positive response in the other conditions of the experiment in which S served, and was sufficient for a positive response two-thirds of the time in this condition. It can be argued that the tendency to make the positive response on such trials was the source of the increase in RT on CM negative trials; under the circumstances it was more difficult than in the Control Condition to inhibit the positive response. The same effect may have been responsible for the increase in RT for the positive responses. Although Ss were accustomed to making the positive response when a match between usual names was found, in this condition a negative response was sometimes required. Hence it may have been more difficult on positive trials to inhibit the negative response. (For a more general discussion of response inhibition as a factor in RT, see Martin, 1967.) Inhibition of inappropriate responses should occur at some stage following the comparison stage; hence factors such as this affecting response inhibition

should not, according to the additive-factor method, interact with the effect of set size. No such interaction was found; the functions for pure negative, CM negative, and positive responses in the Physical Identity condition were parallel.

A Second Look at Previous Results

In the study reported here there were three tests of the kind of representations used for the comparison stage. Two of them clearly indicated that the representations are names, and the third pointed in that direction. In light of these results, what can be said about those studies that indicated images are used?

Most of the previous evidence was relatively indirect. For example, interpretation of the experiments showing similar scanning processes for material without well-learned names (e.g., Sternberg, 1969a, Exp. 4; Briggs & Blaha, 1969) was based on the assumption that Ss did not have names or verbal labels to use for such materials. But it is a uniquely human ability to assign names to things, so the assumption may be faulty. In fact, Briggs (1970) has reported that his Ss voluntarily mentioned verbal labels they had assigned to some of the figures in his experiment. Finally, a logarithmic, rather than linear, relationship between RT and set size was found in one such experiment (Swanson & Briggs, 1969), suggesting that an altogether different search process was used. Thus the evidence from this line of research is equivocal at best.

Attempts to determine the nature of the representations by finding effects of visual or acoustic similarity have been frustrated by conflicting results. Chase & Posner (1965) found an effect of visual

similarity, but Chase & Calfee (1969), using a more powerful experimental design, failed to find such an effect. Neither of those studies found an effect of acoustic similarity. The present results indicate that names or verbal labels are used, so effects of acoustic (or articulatory) similarity might be expected. However, since subvocal rehearsal can be ruled out as a factor in the scanning process, one perhaps should not be surprised at not finding such effects. The trace in STM might be an abstract verbal representation which is neither purely auditory nor articulatory. This possibility has been discussed by Wickelgren (1969).

Perhaps the most difficult finding to reconcile with the present results is Sternbeg's (1967) finding of an effect of stimulus quality on the comparison rate. If the scanning process involves the name of the probe, noise added to degrade its visual image should affect only the encoding time. Perhaps the possibility of a Type I error in that experiment should be considered. A careful examination of Sternberg's data reveals that the slope of the control (intact) function increased from 35.6 to 37.2 ms per item from the first session to the second. In the previous experiments (Sternberg, 1966), slopes of 37.9 and 38.3 ms per digit were found. Hence the slope of the control function on the first session was somewhat lower than usual. Use of the average of the other slopes given above might be a better estimate of the true value, and would reduce the value of _t_ used for the _t_ test. In addition, the standard error of the difference between the intact and degraded slopes on the first session (that is, the denominator of the _t_ test) was somewhat smaller for the first session ($\pm$ 2.4 ms) than for the second session ($\pm$ 3.8 ms). That

factor might also have contributed to producing a spuriously large value of $\underline{t}$. A replication of this study, conducted as carefully as the original experiment, would be valuable.

Conclusions

The present results clearly indicate that the representations used in the comparison stage are not visual in nature, at least when the delay between the positive set and the probe is long enough to rule out physical matches like those reported by Posner (1969). In attempting to reconcile this conclusion with previous results, one might suppose that the actual representation is a complex one including both visual and non-visual information. This possibility is apparently ruled out, however, by the results of the Physical Identity Condition. If visual information could be used, it should have been used in that condition to facilitate scanning. The slow scanning rate obtained suggests that visual information was not used. The same condition provides evidence of the presence of non-visual information in the representation; the increase in RT for CM negative trials must have been caused by the name shared by the upper and lower case versions of a particular letter. Thus the present results seem to imply that the probe is recognized (its identity is determined), and its sensory representation is lost, before the comparison stage begins.

The conclusion that the representations are not visual leaves a large class of possibilities. The terms "name" and "verbal label" have been used in the foregoing to refer to these possible representations only for convenience of exposition, and they are too restrictive. Almost any kind of representation based on S's previous experience with the stimulus

character might be used. Of course, these terms could be descriptive of the actual representation, for example, one reasonable possibility is an articulatory encoding of the spoken name of the character. But the representation could instead be a non-verbal abstraction or concept. The present data require only that the representations of upper and lower case versions of the same letter be sufficiently similar to account for the interference found in the Physical Identity Condition.

The distinction between visual and non-visual representations is an important one. If scanning were based on truly visual representations, then the comparison stage could be considered as a mechanism for pattern recognition. Since Ss reported rehearsing the names of the positive set items, the use of visual representations for comparison would imply that visual representations of the positive set items were held along with their names in STM. A match between a visual representation of the probe and a corresponding representation of some member of the positive set could then result in activation of its associated name, and recognition (or identification) of the probe would be achieved. But the present results indicate that recognition of the probe is achieved before the comparison process begins. Hence the high-speed scanning process must be viewed as a mechanism for the examination of recoded (verbal or conceptual) information in STM.

APPENDIX

INSTRUCTIONS TO SUBJECTS

General Instructions

This experiment is designed to test a theory about memory. I will explain more about it after you have served as a subject if you are interested, but for now please just listen carefully to the instructions.

Your task is very simple. On each trial a short list of letters will be displayed on the upper part of the screen in front of you. The list may contain only one letter, or as many as five. The first one will be displayed on the left side of the screen, the second one to the right of the first one, and so on. After the complete list has been displayed, there will be a short delay, and a rectangle will appear in the center of the screen. About one second later, a test letter will appear in the rectangle. Your task is simply to indicate whether that letter was one of the letters in the list presented at the beginning of the trial. If the letter was in the list, respond "yes" by pressing the right key in front of you with your right forefinger. If the letter was not in the list, respond "no" by pressing the left key with your left forefinger. Between trials please keep your forefingers resting lightly on the keys so you can respond as quickly as possible.

As you can see, the task is easy and you should be able to respond correctly on almost every trial. It is important that you do so. I want you to respond as quickly as you can while maintaining a high level of accuracy. Try to be fast, but don't try so hard that you make unnecessary errors.

At the end of each trial, after your response, the word "correct" or "error" will appear in the lower left corner of the screen, indicating whether your response was correct.

One more thing. In order to prevent you from being distracted by noises in the main room I want you to wear these earphones. In them you will hear a soft hissing sound which should cover up any distracting noises. In addition, I can interrupt the hissing sound and talk to you through them from the main room. If you want to say something to me, you can do so by just turning your head and speaking directly at this intercom.

Upper Case Control Group Subjects Only

This first block of trials is for warm-up and practice. All of the letters you see will be lower case. Try to be quick but without making errors. Any questions?

Lower Case Control Group Subjects Only

This first block of trials is for warm-up and practice. All of the letters you see will be upper case. Try to be quick but without making errors. Any questions?

Before Upper Case Control Condition Blocks

For the next two blocks of trials, all of the letters you see will be upper case. Please be accurate, but be quick.

Before Lower Case Control Condition Blocks

For the next two blocks of trials, all of the letters you see will be lower case. Please be accurate, but be quick.

Before Physical Identity Condition Blocks

For the next two blocks of trials, some of the letters in the list will be upper case and some lower case. The case is important. You are

to respond "yes" only if the test letter is exactly the same as a letter in the list. For example, if an upper case "A" is in the list, and the test letter is a lower case "a", the correct response is "no", the left key. Is that clear?

Before Name Identity Condition Blocks

For the next two blocks of trials, conditions will change a little. When the list is presented, both the upper and lower case of each letter in the list will appear. The lower case will be right below the upper case, and both will come on at the same time. The test letter may be either upper or lower case, but it doesn't matter. The case of the test letter is irrelevant. You are to respond "yes" if that letter was in the list. Is that clear?

REFERENCES

Atkinson, R. C., & Shiffrin, R. M. Human memory: A proposed system and its control processes. In K. W. Spence and J. T. Spence (Eds.), The psychology of learning and motivation: Advances in research and theory. Vol. 2. New York: Academic Press, 1968.

Bower, G. H. Notes on a descriptive theory of memory. In D. P. Kimble (Ed.), Learning, remembering, and forgetting. Vol. II. New York: New York Academy of Sciences, 1967.

Bracey, G. W. Two operations in character recognition: A partial replication. Perception and Psychophysics, 1969, 6, 357-360.

Briggs, G. E. Personal communication, 1970.

Briggs, G. E., & Blaha, J. Memory retrieval and central comparison times in information processing. Journal of Experimental Psychology, 1969, 79, 395-402.

Chase, W. G., & Calfee, R. C. Modality and similarity effects in short-term recognition memory. Journal of Experimental Psychology, 1969, 81, 510-514.

Chase, W. G., & Posner, M. I. The effect of auditory and visual confusability on visual and memory search tasks. Paper read at Midwestern Psychological Association, Chicago, May, 1965.

Conrad, R. Acoustic confusions in immediate memory. British Journal of Psychology, 1964, 55, 75-84.

Corballis, M. C. Serial order in recognition and recall. Journal of Psychology, 1967, 74, 99-105.

Crowder, R. G. Short-term memory for words with a perceptual-motor interpolated activity. Journal of Verbal Learning and Verbal Behavior, 1967, 6, 753-761.

DeRosa, D. V., & Morin, R. E. Recognition reaction time for digits in consecutive and nonconsecutive memorized sets. Journal of Experimental Psychology, 1970, 83, 472-479.

Donders, F. C. Over de snelheid van psychische processen. Onderzoekingen gedaan in het Physiologisch Laboratorium der Utrechtsche Hoogeschool, 1868-1869, Tweede reeks, II, 92-120. Transl. by W. G. Koster in W. G. Koster (Ed.), Attention and performance II. Amsterdam: North-Holland, 1969.

Egeth, H. Selective attention. Psychological Bulletin, 1967, 67, 41-57.

Koster, W. G. (Ed.) Attention and performance II. Amsterdam: North-Holland, 1969.

Landauer, T. K. Rate of implicit speech. Perceptual and Motor Skills, 1962, 15, 646.

Martin, E. Formation of concepts. In B. Kleinmuntz (Ed.), Concept attainment and the structure of memory. New York: Wiley, 1967.

Morin, R. E., DeRosa, D. V., & Stultz, V. Recognition memory and reaction time. In A. F. Sanders (Ed.), Attention and performance. Amsterdam: North-Holland, 1967.

Morin, R. E., DeRosa, D. V., & Ulm, R. Short-term recognition memory for spatially isolated items. Psychonomic Science, 1967, 9, 617-618.

Posner, M. I. Abstraction and the process of recognition. In J. T. Spence & G. H. Bower (Eds.), Advances in learning and motivation. New York: Academic Press, 1969.

Posner, M. I., Boies, S. J., Eichelman, W. H., & Taylor, R. L. Retention of visual and name codes of single letters. Journal of Experimental Psychology Monograph, 1969, 79 (No. 1, Part 2).

Posner, M. I., & Keele, S. W. Decay of visual information from a single letter. Science, 1967, 158, 137-139.

Posner, M. I., & Rossman, E. Effect of size and location of informational transforms upon short-term retention. Journal of Experimental Psychology, 1965, 70, 496-505.

Posner, M. I., & Taylor, R. L. The subtractive method applied to separation of visual and name components in multi-letter arrays. In W. G. Koster (Ed.), Attention and performance II. Amsterdam: North-Holland, 1969.

Smith, M. Theories of the psychological refractory period. Psychological Bulletin, 1967, 67, 202-213.

Sperling, G. The information available in brief visual presentations. Psychological Monographs, 1960, 74, (11, Whole No. 498).

Sperling, G. Successive approximations to a model for short-term memory. In A. F. Sanders (Ed.), Attention and performance. Amsterdam: North-Holland, 1967.

Sternberg, S. High-speed scanning in human memory. Science, 1966, 153, 652-654.

Sternberg, S. Two operations in character-recognition: Some evidence from reaction-time measurements. Perception and Psychophysics, 1967, 2, 45-53.

Sternberg, S. Memory-scanning: Mental processes revealed by reaction-time experiments. American Scientist, 1969, 57, 421-457. (a)

Sternberg, S. The discovery of processing stages: Extensions of Donders' method. In W. G. Koster (Ed.), Attention and performance II. Amsterdam: North-Holland, 1969. (b)

Swanson, J. M., & Briggs, G. E. Information processing as a function of speed versus accuracy. Journal of Experimental Psychology, 1969, 81, 223-229.

Taylor, R. L. Comparison of short-term memory and visual sensory analysis as sources of information. Journal of Experimental Psychology, 1969, 81, 515-522.

Tversky, B. Pictorial and verbal encoding in a short-term memory task. Perception and Psychophysics, 1969, 6, 225-233.

Waugh, N. C., & Norman, D. A. Primary memory. Psychological Review, 1965, 72, 89-104.

Wickelgren, W. A. Auditory or articulatory coding in verbal short-term memory. Psycholgoical Review, 1969, 76, 232-235.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
University of Michigan, Human Performance Center
Department of Psychology
Ann Arbor, Michigan

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. REPORT TITLE

THE REPRESENTATION OF THE STIMULUS IN CHARACTER CLASSIFICATION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Scientific Interim

5. AUTHOR(S) (First name, middle initial, last name)

Blake L. Wattenbarger

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1970	55 plus viii	35

8a. CONTRACT OR GRANT NO. AF49(638)1736 (ARPA)

b. PROJECT NO. 461

c. 61101D

d. 681313

9a. ORIGINATOR'S REPORT NUMBER(S)
~~Technical Report No. 22~~
~~[illegible]~~

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
AFOSR-TR- 71-0430

10. DISTRIBUTION STATEMENT
1. This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES THESIS
University of Michigan, Human Performance Center, Department of Psychology, Ann Arbor, Michigan

12. SPONSORING MILITARY ACTIVITY
Air Force Office of Scientific Research, 1400 Wilson Boulevard (NL)
Arlington, Virginia 22209

13. ABSTRACT

In the character classification task, the S is required to press one of two response keys to indicate whether or not the stimulus character is a member of a previously memorized set of characters. Reaction time (RT) in this task has been found to be a linear increasing function of the number of characters in the memorized set. It has been inferred from this result that part of the RT is occupied by a serial comparison stage in which an internal representation of the stimulus is compared with similar representations of the memorized characters.

The present study was designed to determine the nature of the representations that are compared. Upper and lower case letters were used as stimuli. In the Physical Identity Condition, S was required to respond on the basis of physical identity of the stimulus with a member of the memorized set; i.e., S gave the negative response unless the stimulus matched in both name and case with a member of the memorized set. In the Name Identity Condition, S's response was based on name identity only; case was irrelevant. In the Control Condition all of the letters were the same case.

Performance in the Name Identity Condition was essentially the same as in the Control Condition. In the Physical Identity Condition, the rate of the serial search was substantially slower. These results indicate that Ss typically use a recoded representation of the stimulus (a name, verbal label, or other abstraction) rather than a purely sensory image for the comparison stage.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

KEY WORDS	ROLE	WT	ROLE	WT	ROLE	WT
Character classification Memory search Encoding in memory Physical identity match Name identity match Visual image						

UNCLASSIFIED

Security Classification

TECHNICAL REPORTS

1. Phillips, L. D. Some components of probabilistic inference. January 1966.
2. Egeth, H. E. Parallel versus serial processes in multidimensional stimulus discrimination. January 1966.
3. Biederman, I. Human performance in contingent information processing tasks. October 1966.
4. Peterson, C. R. & Beach, L. R. Man as an intuitive statistician. November 1966.
6. Smith, E. E. Choice reaction time: An analysis of the major theoretical positions. January 1967.
7. Reicher, G. M. Perceptual recognition as a function of meaningfulness of stimulus material. February 1968.
8. Ligon, E. The effects of similarity on very-short-term memory under conditions of maximal information processing demands. May 1968.
9. Triggs, T. J. Capacity sharing and speeded reactions to successive signals. August 1968.
10. Tversky, B. G. Pictorial and verbal encoding in short-term memory. October 1968.
11. Lively, B. L. The Von Restorff effect in very-short-term memory. December 1968.
12. Greeno, J. G. How associations are memorized. December 1968.
13. Swensson, R. G. The elusive tradeoff: Speed versus accuracy in choice reaction tasks with continuous cost for time. December 1968.
14. Bjork, R. A. Repetition and rehearsal mechanisms in models for short-term memory. May 1969.
15. Kamlet, A. S. Processing of sequentially presented signals in information-combining tasks. June 1969.
16. Pollatsek, A. W. Rehearsal, interference, and spacing of practice in short-term memory. July 1969.
17. Garskof, M. H. The effect of spacing and variation of repetition in short-term memory. August 1969.
18. Shulman, H. G. Presentation rate, retention interval, and encoding in short-term memory for homonyms, synonyms, and identical words. September 1969.
19. Du Charme, W. M. A responsive bias explanation of conservative human inference. December 1969.
20. McCormack, P. D. Monitoring eye movements during the learning of paired-associate lists. March 1970.
21. Goodman, B. C. Risky decisions by individuals and groups. June 1970.

MEMORANDUM REPORTS

1. Fitts, P. M. Cognitive factors in information processing. February 1967.
2. Melton, A. W., Sameroff, A., & Schubot, E. D. Short-term recognition memory. May 1967.
3. Martin, E. Responses to stimuli in verbal learning. October 1967.
4. Melton, A. W. First annual report: Human information handling processes. June 1968.
5. Jahnke, J. C. The Ranschburg paradox. July 1968.
6. Greeno, J. G. Theory of graphs on sets with applications to problem solving and understanding. October 1968.
7. Edwards, W. A bibliography of research on behavioral decision processes to 1968. January 1969.
8. Melton, A. W. Second annual report: Human information handling processes. June 1969.
9. Greeno, J. G. A cognitive interpretation of negative transfer and forgetting of paired associates. November 1969.
10. Martin, E. Associative interference theory and spontaneous recovery. November 1969.